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DEVELOPMENT OF PROTOTYPE PRODUCTION ESR FACILITIES

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July 1977

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This report describes the procedures employed to produce and develop a technique to manufacture Electroslag Refined Hollows under a contract granted to the Nutek Corp., Washington, Pa. The report describes the approaches taken together with the results obtained for each approach. Drawings and tooling designs are included in the report.

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SUBJECT: Final Technical Report

TO: Commander
U.S. Army Armament Command
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Rock Island, Illinois

Project No: 6747550

Project Title: Development of Prototype Production ESR Facilities

Project Officer: Dr. V. J. Colangelo

Statement of the Problem: The purpose of this program was to establish a reproducible and highly cost effective manufacturing process for electroslag casting of hollow ingot preforms required as starting material for ordnance components.

Background and Introduction: The inherent flexibility of electroslag remelting (ESR) systems permits establishment of novel techniques of manufacturing shaped castings. Unlike in conventional foundry methods, electroslag castings are made in water-cooled metal molds by remelting of consumable electrodes in suitable slags and refining the metal prior to its solidification. The electroslag casting method lends itself to the production of near net shapes, such as hollow preforms, having smooth internal and external surfaces. However, the cost effectiveness of the ESR hollow ingot casting process and precise designs of a workable system are not readily available to the industry.

Approach to the Problem: The experimental phase was conducted at Nutek, Inc. The work scope of this program was divided into two phases. Phase I included, but was not limited to the following tasks:

(1) Design and assembly of experimental tooling for the manufacture of sub-scale ESR hollow ingots.

(2) Evaluation of different mandrel designs and slags for mutual compatibility enhancement of the quality of the hollow ingot and operational safety of the system.

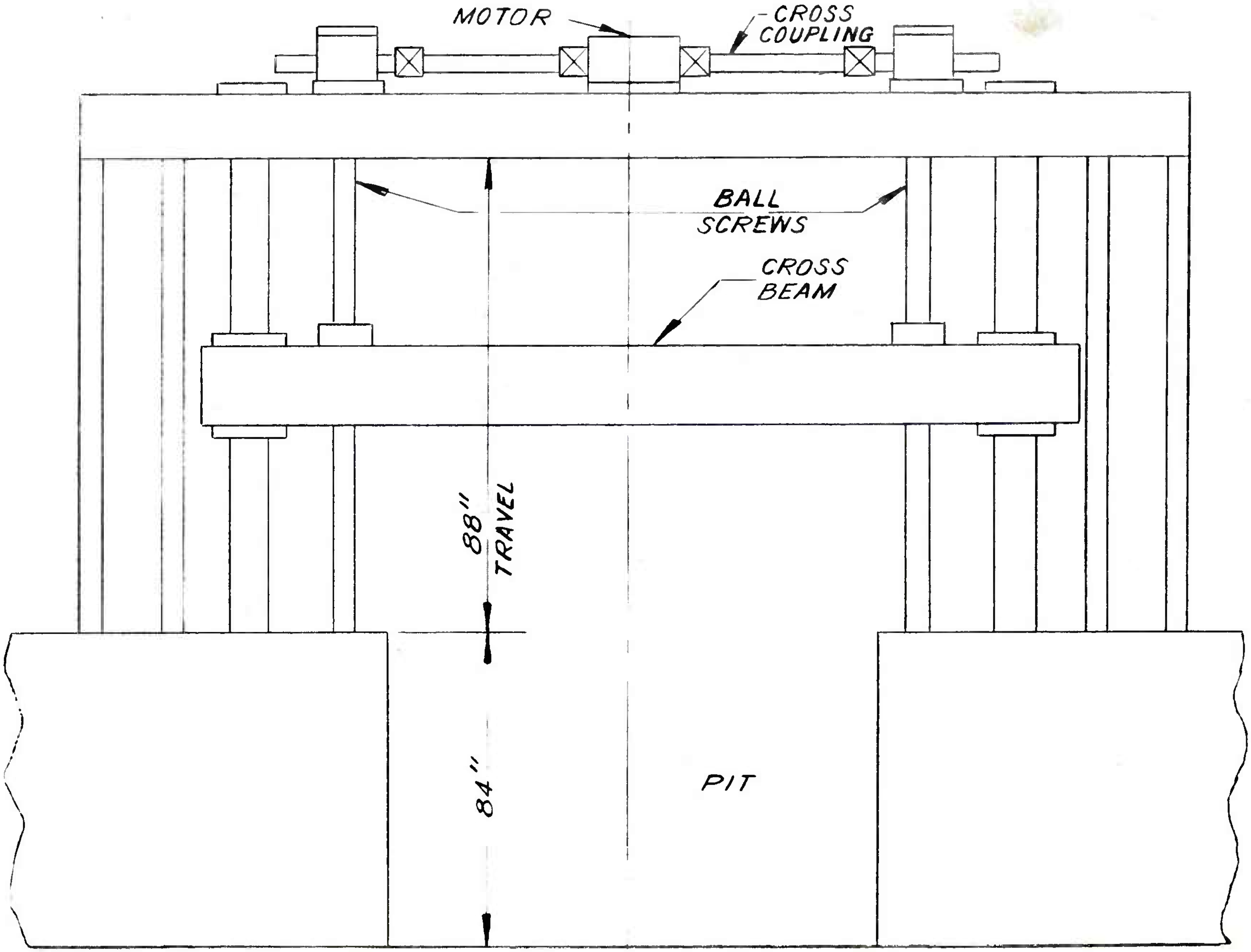

FIGURE 1. SCHEMATIC OF GANTRY TYPE ESR FURNACE
USED IN THIS PROGRAM

(3) Determination of electrode size, number, weight and evaluation of least cost manufacturing techniques.

(4) Formulation of concepts of producing thin-walled hollow ESR ingots.

(5) Provide a comparative economic analysis and further justification for manufacturing hollow preforms by the ESR hollow ingot casting system and conventional method using solid ingots produced via ESR or other methods.

Phase II objectives were to manufacture finalized design toolings and establish procedures for the production of low cost ESR hollow preforms.

Available ESR Facility

The ESR furnace available for use in this program is a gantry type, electrode support framework straddling a rectangular shaped pit. The electrode to be remelted is mounted on a cross-beam which travels up and down over two ball screws otherwise known as jactuators. A schematic of this gantry type ESR furnace is shown in Figure 1.

The ball screw movement is activated by an AC variable speed motor which is coupled to a 20:1 ratio reduction gear. The cross-beam moves over a span of 72 inches although the total length of the ball screw is 88 inches.

The maximum length of electrode which can be conveniently hung and remelted is 130 inches. Maximizing the weight of the ESR ingot which can be produced in this set-up involves certain complicated procedures.

The electrode mounting technique employed requires emplacement of the electrode (or electrodes) with mold at a location away from the furnace. The mold dolly is then pushed under the furnace cross-beam thus enabling pick-up and attachment of the electrode stinger into the holder.

These manipulations introduced certain built-in constraints as regards (a) mandrel deployment and (b) vertical movement of a large funnel shaped mold.

The final pilot scale equipment set-up plans devised for ESR casting hollow ingots, therefore, involved the use of a straight sided (not funnel shaped) 16-inch diameter static mold; two types of rising mandrels; and multiple, flat electrodes. Prior to arriving at this final system design, several exploratory electroslag melting studies were conducted using movable single molds, movable stacked molds, each of a different diameter. These exploratory ESR melting studies conducted are as described herein.

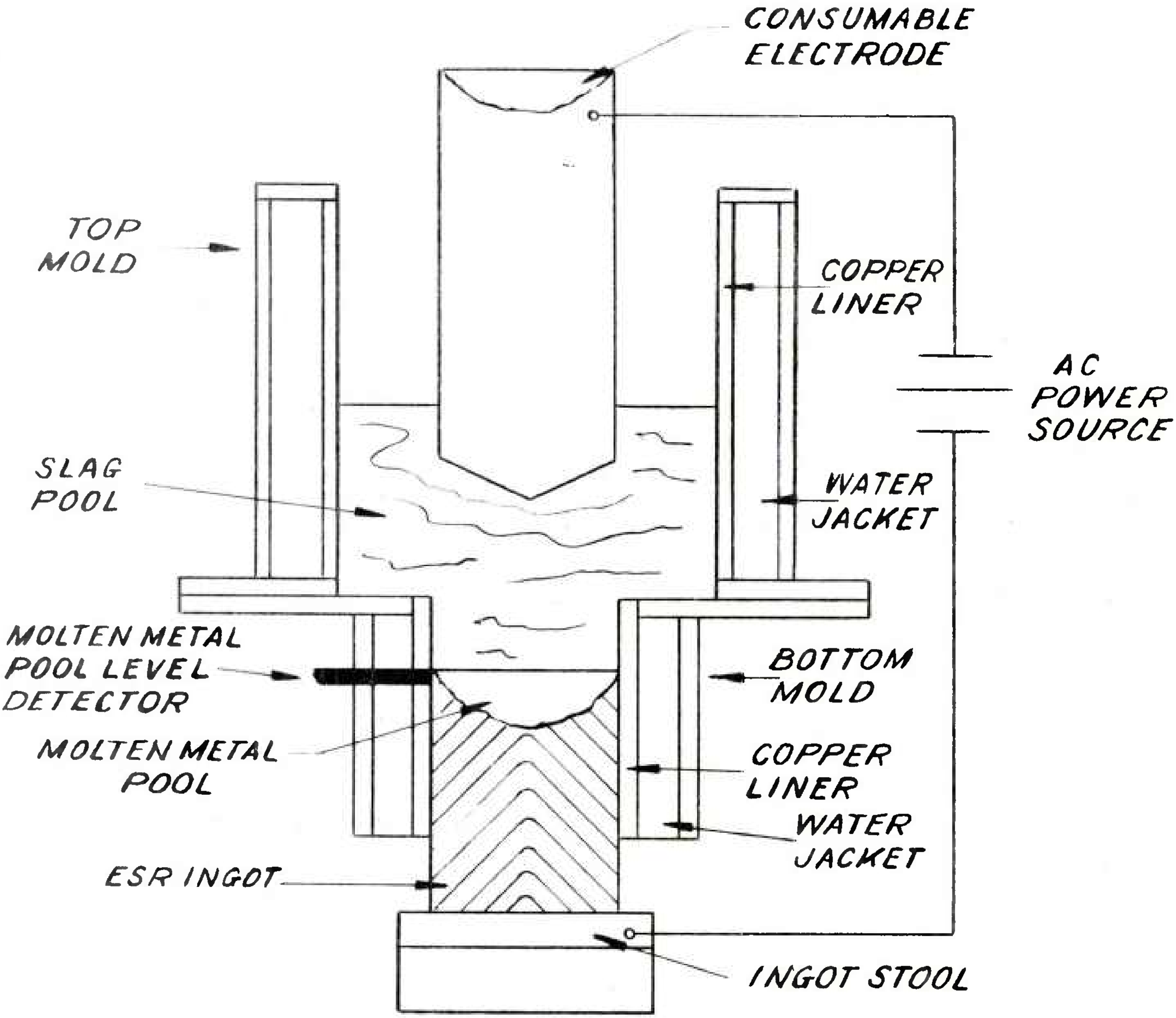

FIGURE 2. SCHEMATIC ILLUSTRATION OF MOVABLE DOUBLE MOLD (FUNNEL MOLD CONCEPT) ESR INGOT PRODUCTION SYSTEM

The melting pit space between the two walls with water supply and drainage pipes mounted on these walls, precluded installation of a sturdy mold moving device. Therefore, an independent mold lifting system was lowered into the pit in front of the ESR stool dolly.

The electrode materials used in these tooling trials and design verification studies were miscellaneous alloy steels. Mold lifting in these studies was limited to a height of at most 20 inches. The ingots made or attempted were 6 inches, 8 inches and 10 inches in diameter.

The 6 inch diameter and 8 inch diameter molds lifted off satisfactorily and enabled the production of small ESR ingots displaying acceptable surface condition. However, the surface developed on these ingots was not as smooth as that produced on an ESR ingot cast in a static water-cooled copper lined mold. The 10 inch diameter mold was too heavy for the lifting mechanism. The mold axis did not coincide with the vertical axis of the ingot. The mold, after lifting approximately 10 inches, would bind the ingot. Therefore, the mold lift system could not be utilized for making ingots larger than 8 inches in diameter.

The next effort conducted was melting of an electrode in a double mold as shown schematically in Figure 2. The 8 inch diameter mold was stacked up on the 6 inch diameter with asbestos gaskets in between the two mold openings. The melting trials in this set-up all ended up in failures because of leakage at the stacking interface of either the flux or the metal. Eventually, both molds were so badly damaged that they had to be taken out of service.

A water-jacketed steel mold of the design as shown in Figure 3 was used in next attempts to cast shaped ingots. These trials were reasonably successful as long as the molten metal level remained in the narrow diameter. Any lack of slag shell around the ingot led to the formation of rough ingot surface and occasionally arcing. It is this parasitic arcing which eventually led to the destruction of the inside steel shell of this mold. The steel shell was only 0.100 inch thick. A minor explosion resulted in the molten flux pool.

Attempts made to develop simple inexpensive sensors for detection of molten metal level did not yield useful results. The sensors used were graphite rods embedded through the water jacket in the inside shell of the mold in such a way that they could differentiate the widely variant conductivities of the slag and the metal. This concept seemed to work when the graphite rod was immersed in the metal pool and withdrawn into the slag. However, in actual ESR melting trials, the two sensors did not provide differential readings of conductivity of the slag and metal pools.

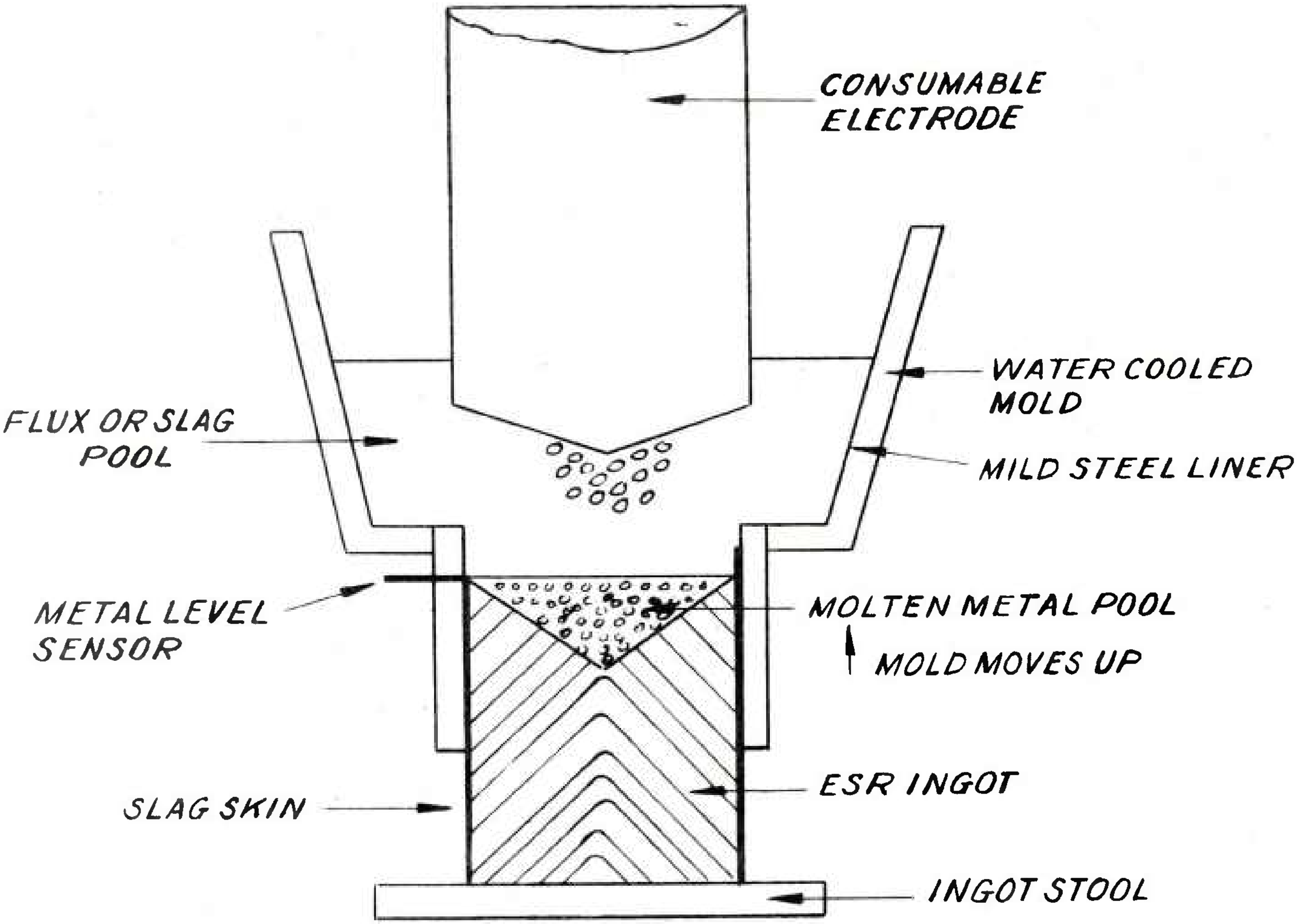

FIGURE 3. SCHEMATIC OF A STEEL FUNNEL MOLD (MOVES UP) ESR INGOT CASTING SET UP

Because the steel mold was heavy, a two-sided support and lift system was used.

An x-ray molten metal scanning device and an isotope device of the types used in continuous casting were priced, but found to be too expensive. Inquiries were also made either to loan or rent one of these scanning devices, but none was available.

The lack of a molten metal level scanning device and large mold support system eventually led to the decision of making hollow ESR ingots in a static straight sided mold. A 16 inch diameter mold available was, therefore, refurbished. This mold was out-of-round and did not have a taper for easy removal of ingots. The mold refurbishing modifications involved machining of the inside liner.

The reasons for refurbishing the 16 inch diameter mold and rejecting the idea of designing and construction of a water cooled funnel mold were as follows:

a. The costs involved were too high (in excess of $14,000 for the mold only).

b. The mold support structure could not be easily accommodated in the pit area.

c. The estimated costs of funnel mold support and vertical movement system exceeded $12,000 for parts and labor.

Once the decision was made to use the existing system and tooling, the essential modifications quickly were made. These system modifications included completion of following tooling and refurbishment tasks:

(1) Machining a taper in an existing 16 inch, 1 ton ingot casting water-cooled copper mold.

(2) Modifications to an existing mold stool for mounting and clamping the 16 inch mold.

(3) Machining a slot in the stool for molten flux entry.

(4) Design, construction and attachment of a molten flux delivery system to the 16 inch mold and its stool.

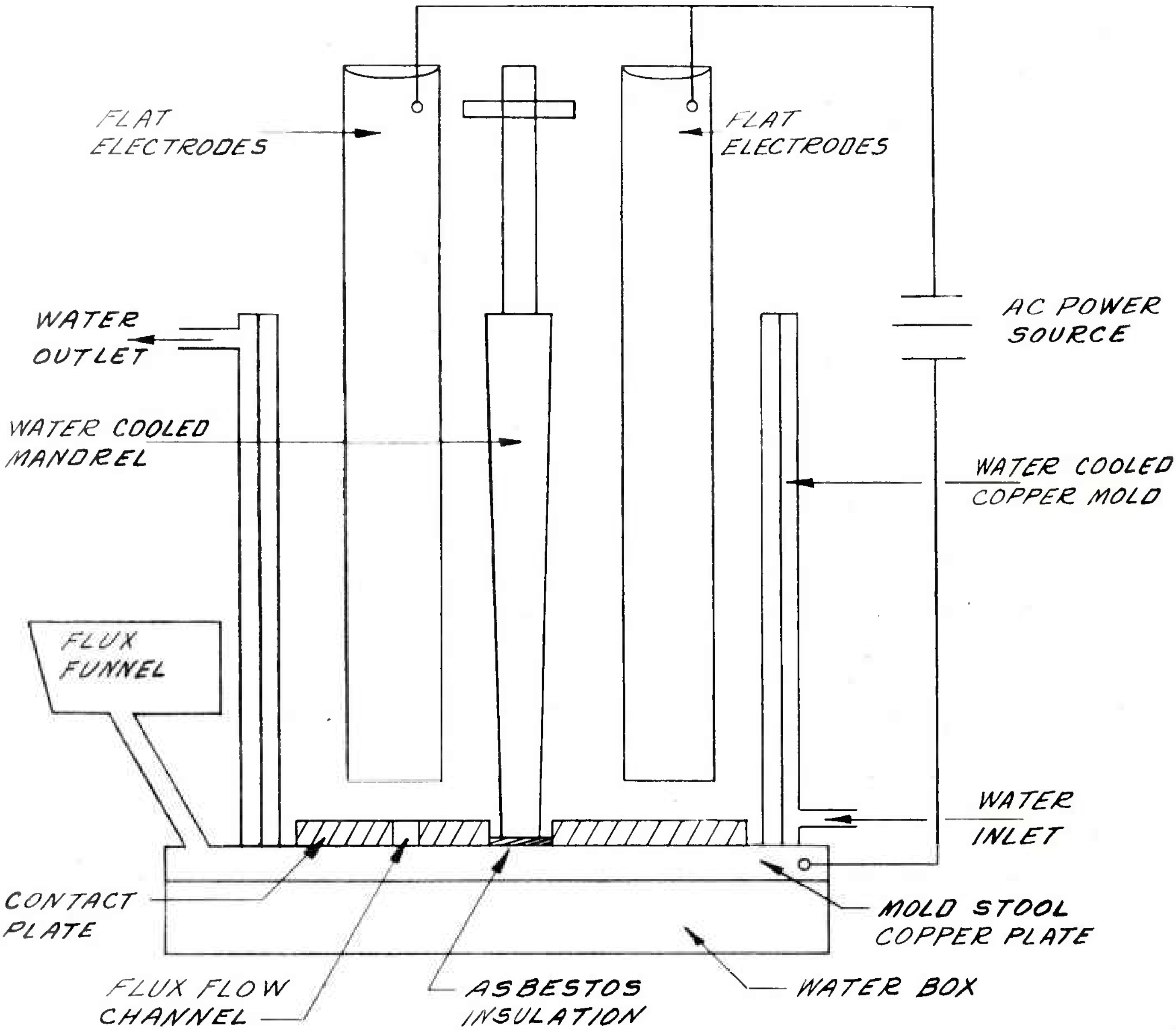

FIGURE 4. SCHEMATIC OF ESR HOLLOW INGOT MANUFACTURING SYSTEM USED IN THIS PROGRAM.

(5) Design, construction and fabrication of a 150 lb., water jacketed crucible for molten flux preparation.

(6) Design, construction, procurement, installation and integration of a 250 KVA power source for molten flux preparation.

(7) Design, construction and commissioning of a molten flux preparation system using a non-consumable electrode with a motorized up and down movement.

(8) Installation of a water cooled bus system for delivery of current in excess of 13,000 amps to a multiple electrode holder of a hollow ESR ingot casting system.

(9) Design, construction, installation and operation of a rotatable water cooled mandrel with fully automated up and down movement within a four-foot span.

(10) Provision of an independent cooling water pumping and circulation system for the mandrel.

(11) Enlargement of cooling water storage, pumping and circulation systems for the 16 inch diameter mold, stool and molten flux preparation crucible.

(12) Fabrication and integration of a larger capacity fume collection and dispensing system for flux preparation and ESR ingot casting.

WATER COOLED MOLD AND FLUX DELIVERY SYSTEM

A schematic of the ingot mold mounted on a water cooled stool with the flux delivery funnel attached to the stool and the mold is shown in Figure 4. A photograph of the actual system used is presented in Figure 5. This system operated satisfactorily most of the time. The difficulty experienced was during the charging of molten flux. Occasionally, a solid crust of flux would lodge in the funnel opening and block further passage of molten flux. Cleaning of the funnel and recharging of molten flux are the remedial steps taken so as to initiate the melt. Graphite crucibles, graphite funnel or a graphite delivery channel, were not used in the molten flux preparation and delivery systems because of the possibility of carbon enrichment of both the flux and the remelted metal.

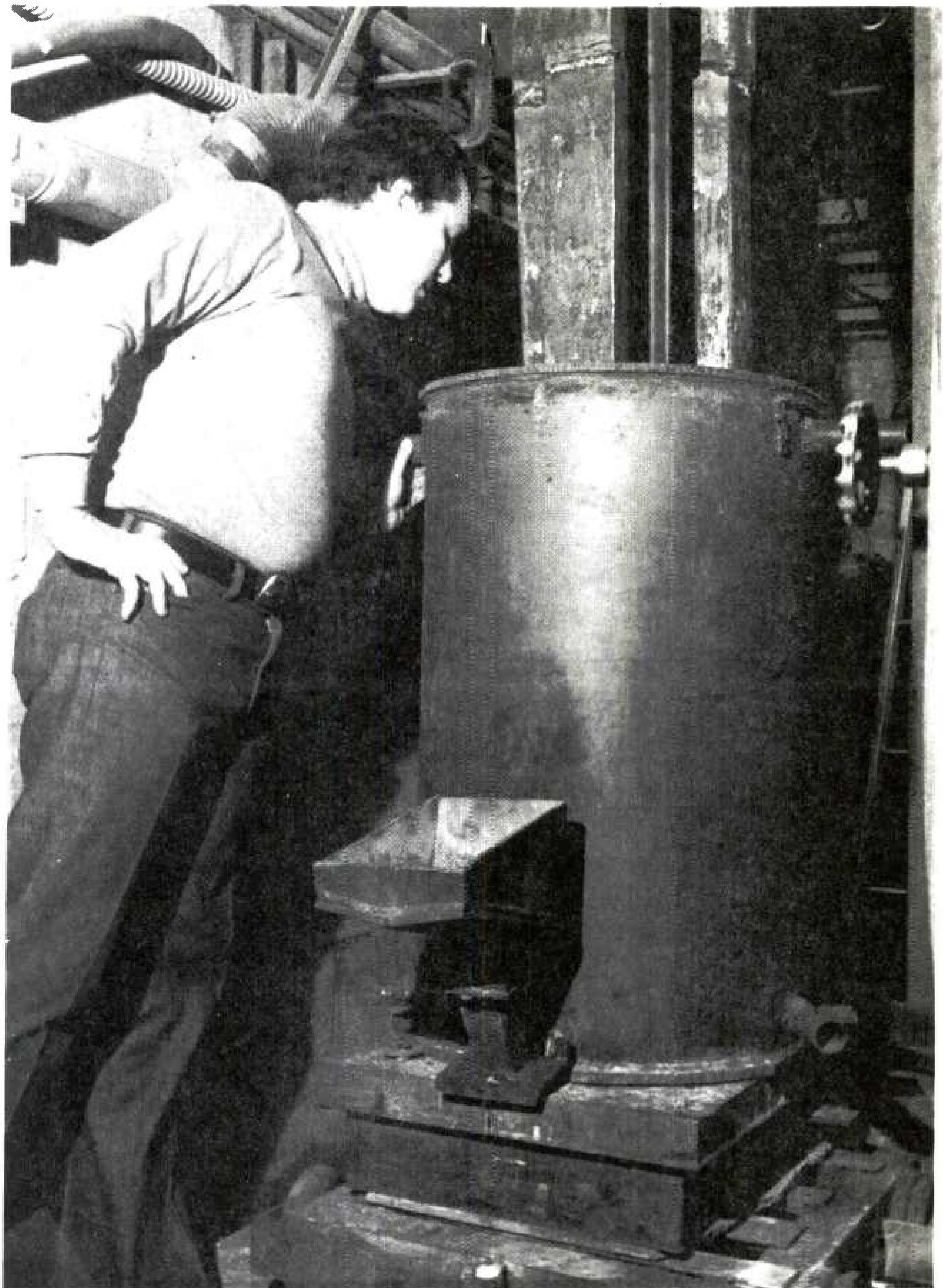

FIGURE 5. ESR HOLLOW INGOT MANUFACTURING SYSTEM

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FLUX PREPARATION CRUCIBLE

The flux preparation system consisted of a 16 inch diameter, 10 inch deep water jacketed copper pot fabricated according to the design shown in Figure 6. The pot is mounted on brackets in such a way that its contents can be poured out simply by tilting. The pot can be moved from one location to another on a dolly.

Molten flux is prepared using a graphite electrode. Normally, the molten flux needed can be prepared within 20 to 15 minutes. For electroslag casting a 16 inch diameter ingot, approximately 110 to 120 pounds of flux has to be premelted. Depending upon the molten density of the flux composition, this weight of flux will provide a flux depth of 5 to 6 inches in the 16 inch diameter mold.

FLUX MELTING POWER SOURCE

The flux melting power source was designed to provide variable current at a constant potential of 50 volts. The current at the start is adjusted at 2,000 amps, which could be increased up to 5,000 amps. The flux melting in the 16 inch water-cooled pot was done at around 3100 amps and the voltage drop,depending upon the flux composition, was between 34 and 42 volts.

The input line voltage to the flux melting power source is 7200 volts.

A transformer steps down this voltage to the required open circuit secondary voltage to 50 volts. Current control is achieved through a special array of thyristors and their associate solid state circuitry rather than through a conventional reactor.

MANDRELS, THEIR DESIGN, FABRICATION, AND MANIPULATION DURING ESR HOLLOW INGOT MANUFACTURE

Mandrels of steel, copper, clad steel and copper, molybdenum alloy and graphite have been used in the casting of ESR hollow ingots. From a cost and reliability viewpoint, copper mandrels seem to be most appropriate for this purpose.

Typical designs of mandrels used in study are presented in Figures 7 and 8. Steel mandrels can be used. However, they can be easily punctured by parasitic arcs. If these punctures occur at or below the molten metal level, a violent explosion may result. If the mandrel

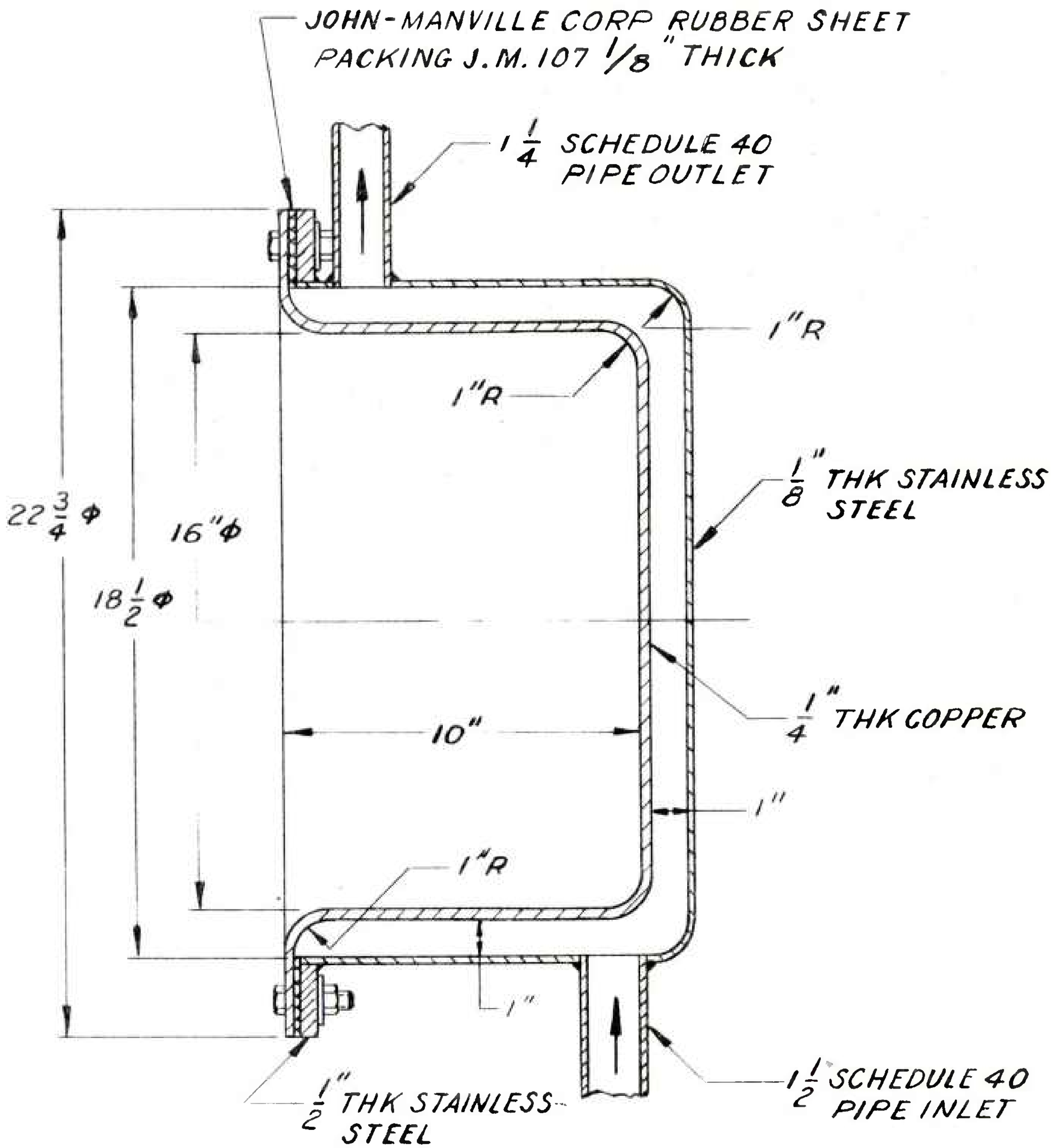

FIGURE 6. DESIGN DRAWING OF THE 16 INCH DIAMETER, 10 INCH DEEP FLUX POT.

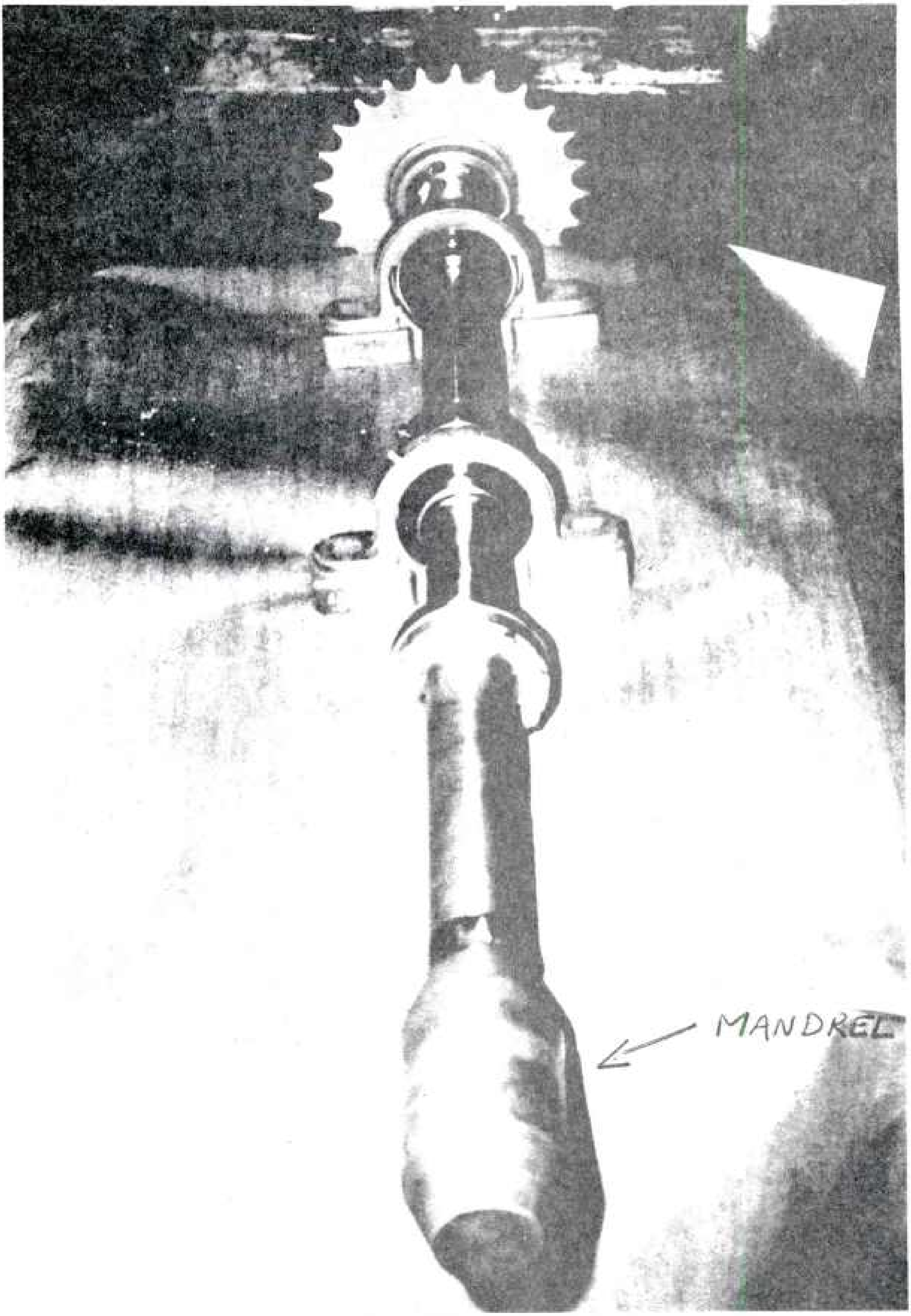

FIGURE 7. STRAIGHT-SIDED MANDREL
(Material-copper Internally water-cooled)

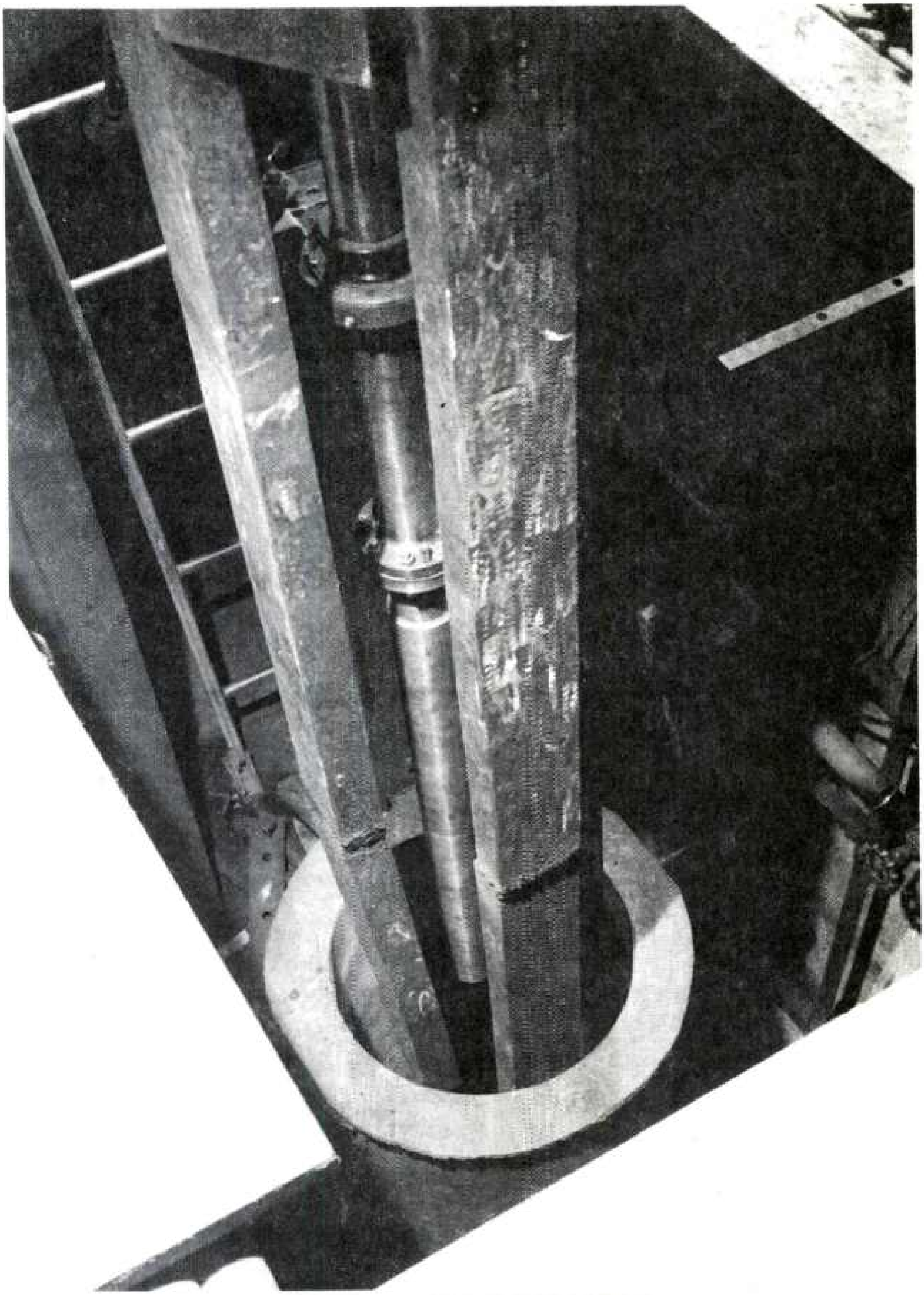

FIGURE 8. TAPERED LONG MANDREL
(Material-copper Internally water-cooled)

develops water leaks above the molten metal level, eruption of flux and disruption of the melt is the likely consequence.

The mandrel should not have weld joints or threaded fit joints in its working column. This segment is the length which is immersed in the flux and the metal pool in order to form the central hole in the ingot. The minimum length of the mandrel should, therefore, be equal to the ingot outside diameter. This is based on the assumption that the depth of the flux pool is equal to one-half of the mold diameter (in molds smaller than 10 inches in diameter, at least a 4 inch deep flux pool) and the metal pool depth is no more than one-half the ingot diameter. To this empirically fixed length of the mandrel, a safety factor of 20 to 40% length must be added to provide a working distance.

The mandrel can be made out of a solid bar of copper in which a hole can be drilled for the circulation of mandrel coolant (water). Tubular copper (wall thickness at least 3/8 inch) can also be used for mandrel construction.

However, the bottom closure plug has to be fitted by machining threads on the plug and inside diameter of the copper pipe. The plug should be secured in place by welding as shown in Figure 9.

The mandrel reciprocation and rotation system which was designed, fabricated and put into operation is shown schematically in Figure 10.

A significant accomplishment of this project is this unique mandrel design. When this mandrel was operated satisfactorily, (i.e. mandrel lift-off rate synchronized with ingot build-up rate) the hollow ingot casting proceded flawlessly. Mandrel rotation had to be stopped prior to its lift-off in order to generate the central hole in the ingot. These observations and conclusions emerged only after the attempted castings of the first and the final ingot in this program.

An improved method of cooling the mandrel is through the use of a finned inlet water pipe located within the copper pipe.

The extensions to the mandrel, such as the hollow shaft, flanges, couplings are made out of stainless steel. Heat resistance is a requirement of the mandrel construction materials, although a heat shield is normally used above the mold openings. Mandrel shaft assembly design is provided in Figure 11.

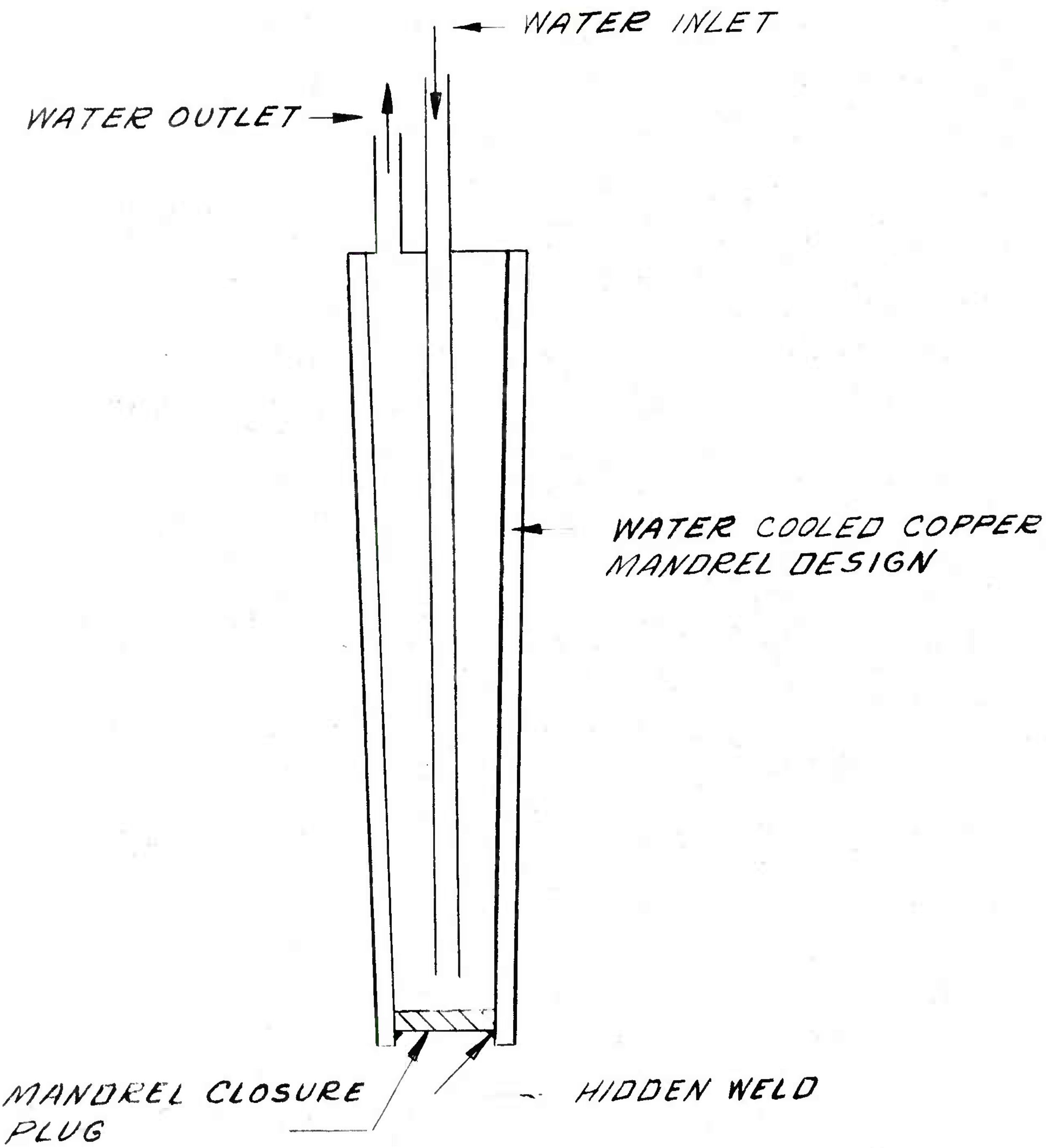

FIGURE 9. SCHEMATIC SHOWING FABRICATION FEATURES OF A LOW COST COPPER MANDREL.

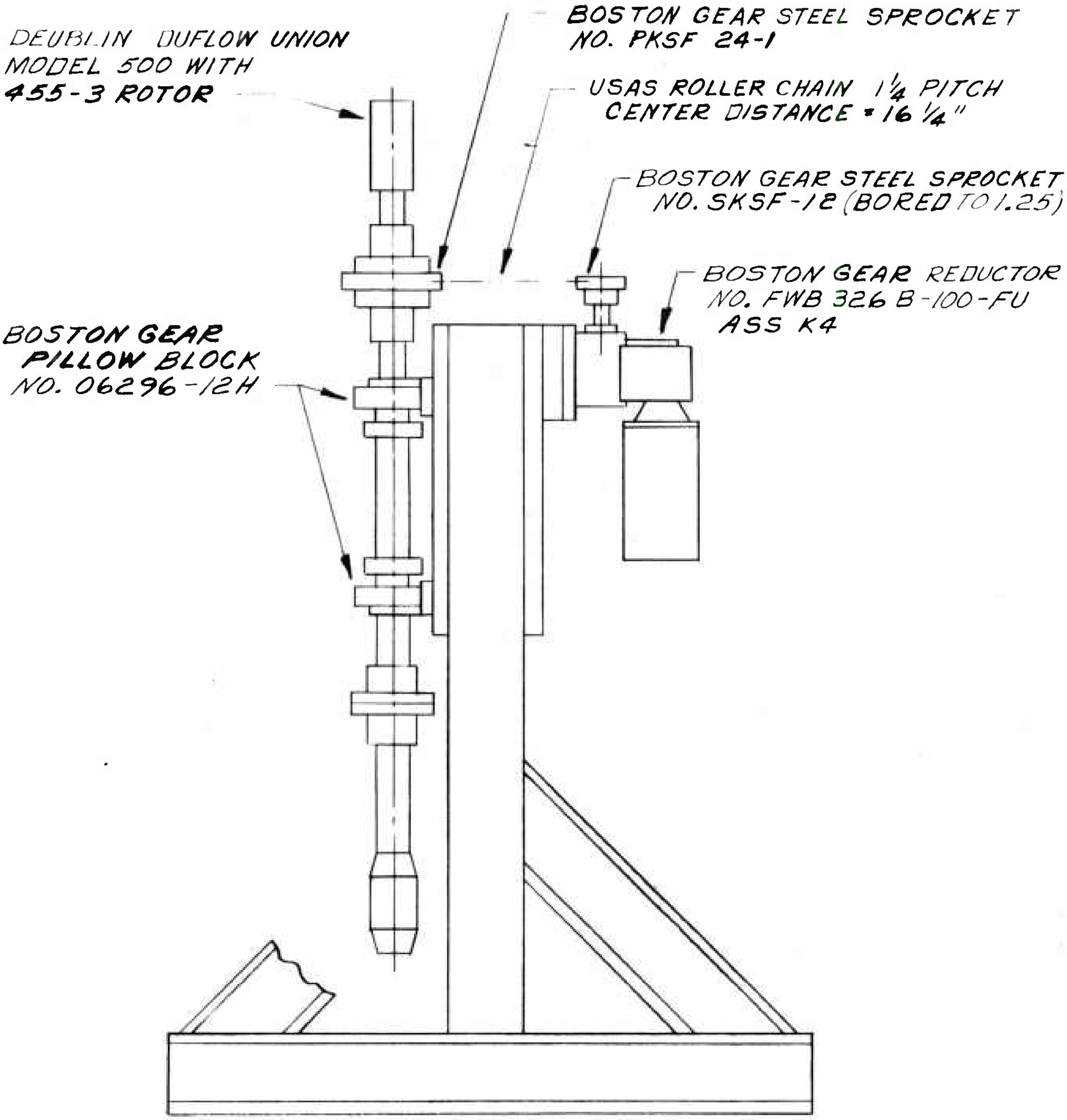

FIGURE 10. DESIGN FEATURES OF A ROTATABLE MANDREL FOR THE MANUFACTURE OF ESR HOLLOW INGOTS.

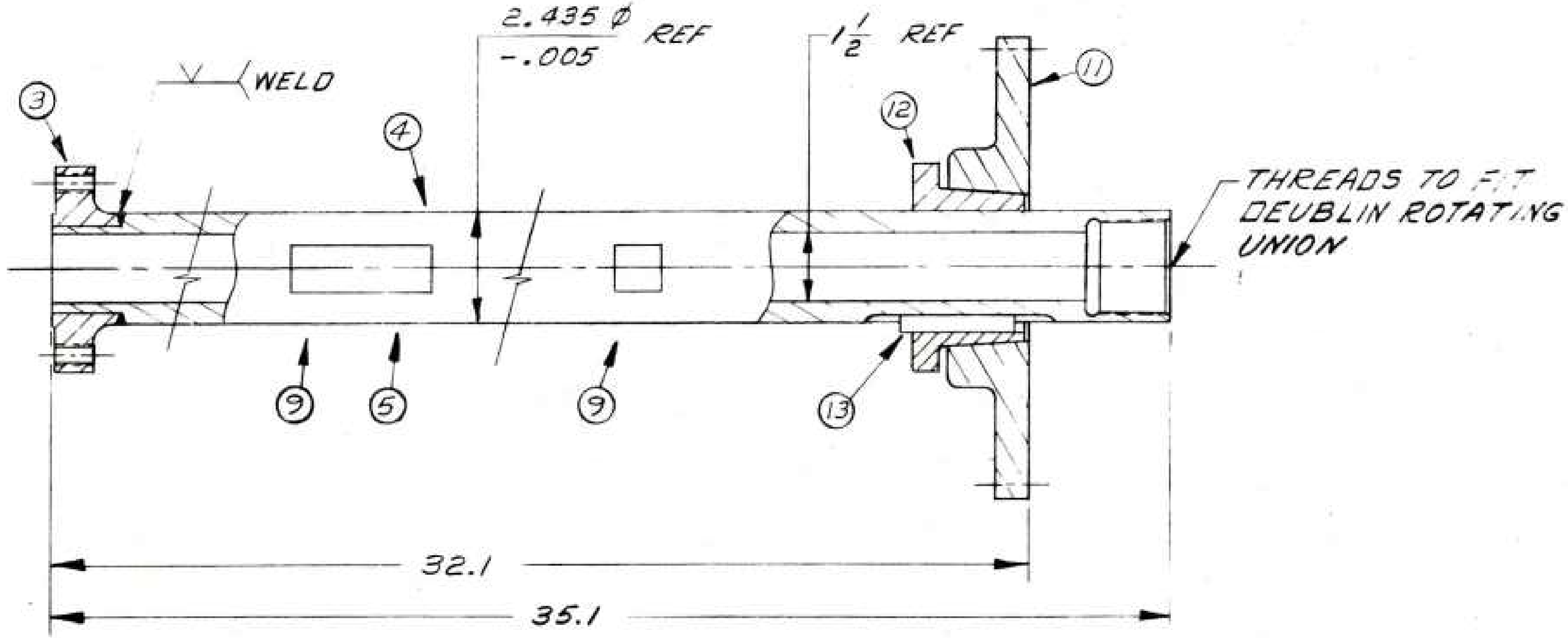

FIGURE 11. MANDREL SHAFT ASSEMBLY DESIGN

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FLUXES FOR CASTING ESR HOLLOW INGOTS

The use of a water cooled mandrel in the flux pool sets up steep temperature gradients in the annulus of the mold wall and the mandrel surface. Fluxes or slags which remain fluid over a wider range of temperature, otherwise known as "long fluxes" offer certain distinct advantages. Four types of ESR fluxes were evaluated in order to determine their suitability for manufacture of good quality ESR hollow ingots. The compositions of the fluxes representing these four types were as follows:

CaF_2 - Al_2O_3 Type (High CaF_2)

1. 70% CaF_2 + 30% Al_2O_3
2. 80% CaF_2 + 20% Al_2O_3

CaF_2 - Al_2O_3 - CaO Type (High CaF_2)

3. 70% CaF_2 + 20% Al_2O_3 + 10% CaO
4. 80% CaF_2 + 15% Al_2O_3 + 5% CaO
5. 60% CaF_2 + 20% Al_2O_3 + 15% CaO + 5% SiO_2

CaF_2 - Al_2O_3 - CaO - MgO Type (Medium CaF_2)

6. 60% CaF_2 + 25% Al_2O_3 + 10% CaO + 5% MgO
7. 50% CaF_2 + 20% Al_2O_3 + 20% CaO + 10% MgO

CaF_2 - Al_2O_3 + CaO + SiO_2 Type (Low CaF_2)

8. 40% CaF_2 + 30% Al_2O_3 + 30% CaO
9. 30% CaF_2 + 40% Al_2O_3 + 18% CaO + 12% MgO

The water cooled copper mandrels used, all operated quite satisfactorily in all 9 aforementioned fluxes. The fluxes which were characterized as "long" are compositions 3,5,6,7, and 9. These fluxes exhibited the potential of providing excellent surface condition on the ingot OD and ID of the ingot. These fluxes were stable at the operating temperature (around 1780°C) for at least 3 hours.

The steel mandrels appeared to survive better in high CaF_2 flux compositions rather than in low CaF_2 type fluxes. SiO_2 addition seemed to increase the occurrence of parasitic arcs.

Graphite mandrels functioned better in low CaF_2 and high CaO flux compositions.

The incidence of parasitic arcing was observed to be markedly lower when graphite was used as mandrel material.

ELECTRODE CONFIGURATION AND COST OPTIMIZATION

The electrode configuration is one of the most important factors which determines the ease or difficulty in the production of ESR hollow ingots. The cost impact of the electrode manufacturing process determines the complexity of the hollow ingot casting system and the overall process economics.

The work has suggested the merits of using multiple electrodes rather than single electrode to ESR cast long hollow ingots. An important advantage of multiple electrodes is in the possibility of distributing the heat uniformly during the process. This provides for the development of smooth surface features on the ingot outside diameter (OD) and the inside diameter (ID) of the central cavity. Multiple electrodes promote uniformity of ingot structural features including the chemical composition and process stability from the start to finish.

Maximization of weight of a given length of electrode is accomplished through the use of flat, rather than the round electrodes. Initially forged flats were used as multiple electrodes. Subsequently, a special technique of casting these flats either in sand molds or in graphite molds was developed. Casting in sand molds should be done with care. Foundry workers often do not allow adequate cooling time for the castings. The first round of flat electrodes produced warped severely. A subsequent set of four, 2"t x 4"w x 88"l flats produced were given adequate cooling time with sand mold and these electrodes turned out to be reasonably straight. Only one flat electrode was cast in a graphite mold.

This experiment was quite successful.

An analysis of various type electrode manufacturing processes and their respective costs was performed as follows:

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(1) A metal charge to prepare a 6 ton electric arc furnace heat of modified 4337 alloy was quoted at \$300 per ton and that in a 25 ton electric arc furnace, at \$280 per ton.

(2) Electric arc furnace processing of this heat costs around \$300 per ton in the 6 ton furnace and around \$260 per ton in the larger 25 ton furnace.

(3) Molten metal cost, therefore, is \$600 per ton in the small furnace and \$540 per ton in the larger furnace.

(4) This heat can be cast (a) in conventional ingot molds for approximately \$40 per ton, or (b) in electrode molds for approximately \$30 per ton or (c) in special permanent molds to produce flats at a cost of around \$100 per ton or (d) in centrifugal casting molds at a cost of around \$150 per ton.

The total cost of cast products assuming an average yield of 90% can be estimated as follows:

6 Ton Heat/Cost per ton of

Rolling or Forging Ingot	Electrode (Large dia. round)	Flat Electrodes	Centrifugally Cast Pipe Electrodes
\$711	\$700	\$778	\$833

25 Ton Heat/Cost per ton of

Rolling or Forging Ingot	Electrode (Large dia. round)	Flat Electrodes	Centrifugally Cast Pipe Electrodes
\$644	\$633	\$711	\$767

The conventionally cast ingot can be forged or directly rolled into flats required for ESR casting of hollow ingots. Forging costs are around \$450 per ton and rolling costs are around \$270 per ton. The rolling operation does not produce flats which are straight. A flattening operation is required. This will add another \$80 per ton to the rolling cost.

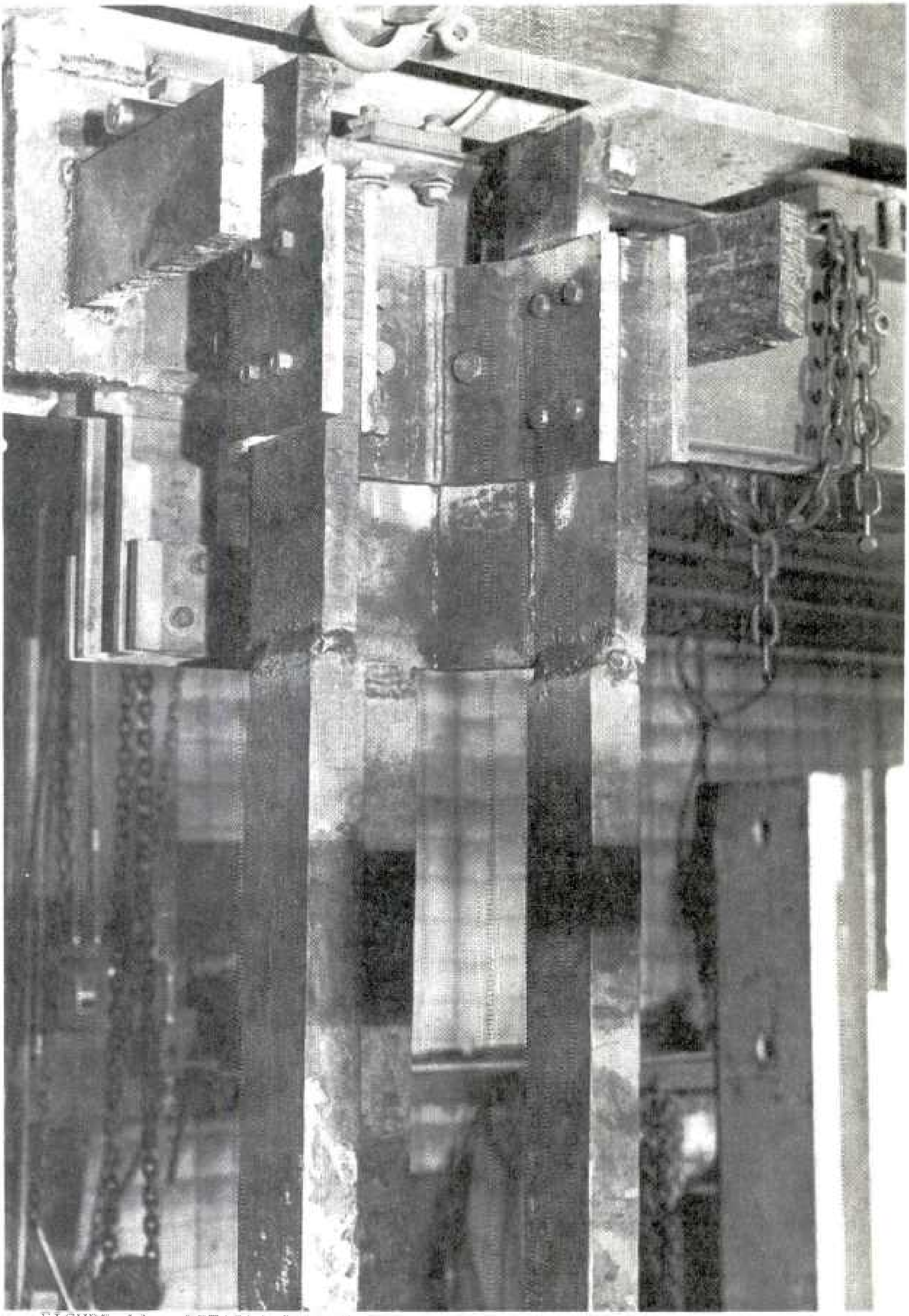

FIGURE 12. DETAILS OF "U" SHAPED MULTIPLE ELECTRODE HOLDER

Thus, the final costs of producing flat electrodes (assuming 100% yield offer forging or rolling) may be estimated as follows:

6 Ton Heat/Cost of producing 2" thick x 4" wide by 80" to 100" long flat electrodes per ton

Rolling	Forging	Special Casting
\$1061	\$1161	\$778

25 Ton Heat/Cost of producing 2" thick x 4" wide x 80" to 100" long flat electrodes per ton

Rolling	Forging	Special Casting
\$994	\$1094	\$711

FINAL SET-UP FOR FEASIBILITY DEMONSTRATION OF MANUFACTURING HOLLOW ESR INGOTS

The final design of the set-up used for casting ESR hollow ingots is as shown in Figures 5, 12 and 13.

Figure 12 shows fabrication details of the multiple electrode holder. The electrode holder consists of two plates of high conductivity copper; each plate bent and shaped as a letter "U". The electrodes are individually welded to a mild steel stub which is also "U" shaped. The contact surfaces of both copper plates and the steel stub are first polished to a mirror finish and then coated with Cool-Amp (a silver paint).

The electrode holder accepts as many as five flat electrodes. Only three electrodes were used for the first hollow ESR ingot melt. Subsequent melts were made using five electrodes.

The mandrel was positioned as shown in Figure 13. It rides up and down in the "U" shaped electrode clamp. The rotation of the mandrel is accomplished through a sprocket wheel mounted on the mandrel holder. A chain attached to a geared motor drives the sprocket wheel. This design was originally intended for operation in a 22 inch diameter funnel shaped moving mold. It is scaled down and modified. However, the rotational speed of the mandrel far exceeded requirements. The cramped quarter in the "U" shaped electrode clamp caused severe arcings between the chain and electrodes - when the latter were not straight. Magnetic interactions were also presumed to be problems which led to arcing, during the initial trial melts. This arcing was completely eliminated in latter trials by bracing the electrodes at different levels with cross members as shown in Figure 13.

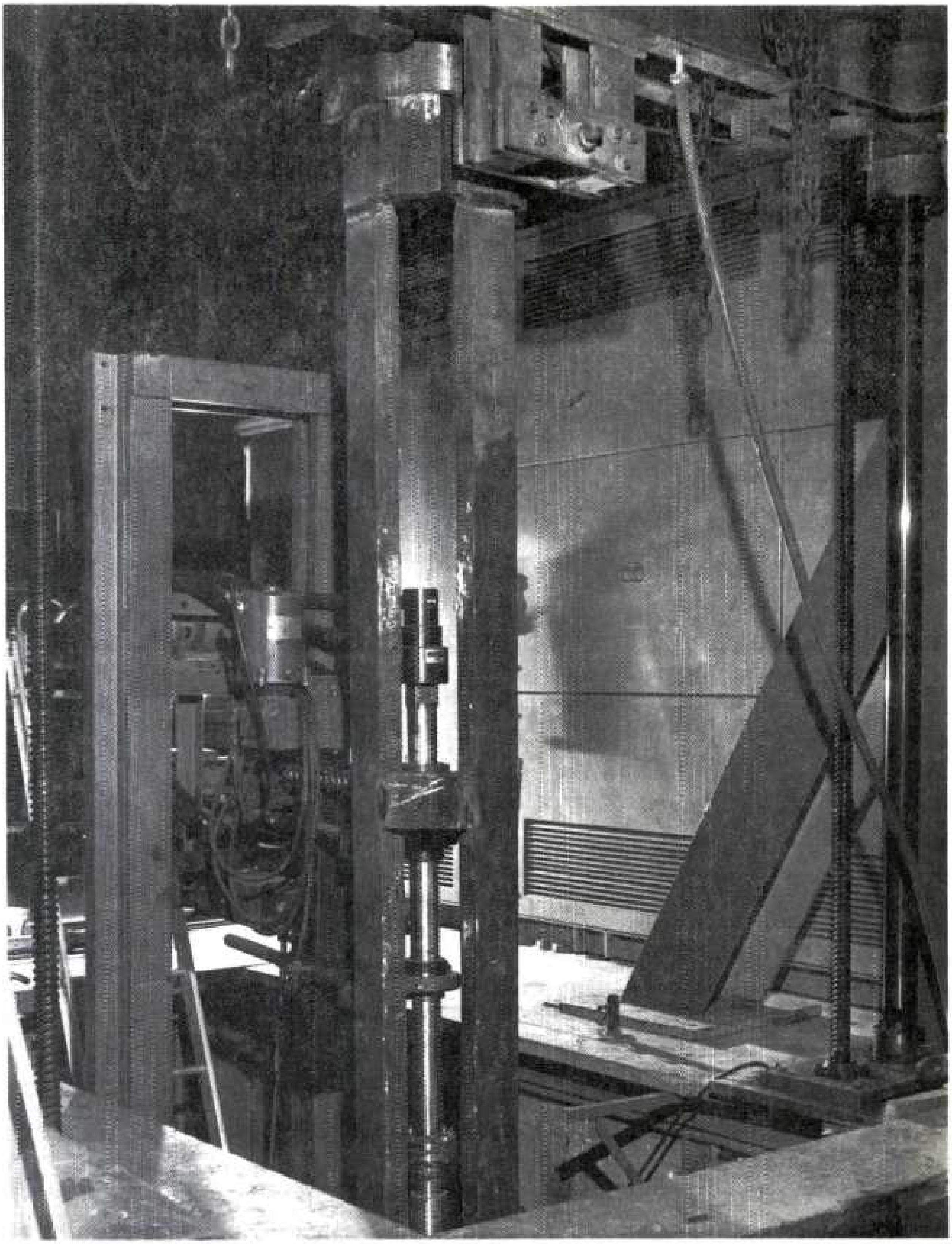

FIGURE 13. MANDREL IN POSITION WITHIN "U" SHAPED ELECTRODE HOLDER

Many cast electrodes received had to be cut and refitted by welding to improve their straightness. The vendor gained proficiency in electrode casting too late in the course of this project work.

ESR HOLLOW INGOT CASTING PROCESS SEQUENCE

The mold with the electrode supported vertically is pushed under the furnace and the electrode is attached to the holder. Then the mandrel is positioned over the mold and centered. This is an imprecise operation and a drawback of the present design.

The mandrel is lowered until it is located within the hole cut in the 1 inch thick bottom contact plate (approximately 15 inch diameter). This contact plate rests on the top copper plate of the stool. The mandrel is insulated from the stool and the contact plate using asbestos sheet.

The flux funnel is then attached and then the electrical connectors from the power source are attached. The electrodes are raised to provide a gap of at least 3-1/2 inches from the bottom contact pad.

The flux is preheated to 1500°F for at least 4 hours prior to the melt. This warm flux is used to prepare the molten flux in the 16 inch pot. The power from a 250 KVA transformer was used when this service became operational in early 1976. Prior to this, the main power source was used both for flux melting in a separate vessel and also for ESR ingot casting.

The availability of flux melting power from an auxiliary power source solved certain complex electrical problems during the ESR melt initiation period.

Soon after charging the molten flux, the current is raised to the required amperage (usually around 9.6KA) for producing a sound ingot in the 16-inch diameter mold.

The electrode immersion in the flux pool is adjusted to achieve the highest stable voltage. These adjustments are normally accomplished within 5 minutes after melt initiation. From then on, the automatic melt monitor takes over the process and maintains a constant rate of melting by controlling the total power delivered to the flux pool. The flux pool depth is maintained nearly constant through a constant rate feeding of dry preheated flux of the same composition but admixed with deoxidizers such as aluminum or misch metal.

Title: Development of Prototype Production ESR Facilities

The successful hollow ingot melts made were those in which the mandrel was rotated during the ESR melt initiation period. The mandrel rotation was stopped prior to its withdrawal from the metal pool. This mishap occurred during the first hollow ingot melting attempt.

Mandrel withdrawal must be started as soon as a metal pool of two-inch depth forms. A miscalculation of electrode melt rate, and the computed height of metal at the start, invariably leads to the mandrel sticking to the bottom plate. When this occurs, the only corrective step that can be taken is to raise the temperature of the metal prior to attempting extraction of the mandrel. If these attempts fail, the mandrel can only be extracted by reheating the ingot and punching it out in an extrusion press.

The first ten minutes after the initiation of a hollow ingot melt is a critical period. If the mandrel lifts off without difficulty, the balance of the hollow ingot melting operation proceeds as smoothly as a solid ingot ESR melt.

The second hollow ingot melting operation was a complete success.

The third and fourth attempts failed because of electrode alignment problems. Severe arcing occurred between the electrodes and the mandrel rotating chain and sprocket wheel.

The final melting attempt proceeded smoothly at first. However, the mandrel alignment was apparently disturbed during the pouring of flux. At first, there was every indication that the mandrel was lifting up. After a while, it was realized that the mandrel had actually tilted forward and was wedged in the hole when a small force was applied to extricate the mandrel, the entire ingot was lifted off the stool which caused melt disruption.

The number of melts made in this program, in order to evaluate various equipment designs, materials and finally to establish a cost effective ESR, hollow ingot manufacturing process are listed in Table I along with a summary of process parameters used.

CONCLUSIONS

This project work resulted in only modest success in the establishment of a manufacturing technique for casting ESR hollow ingots.

TABLE I

ESR MELTING TRIALS IN SUPPORT OF HOLLOW INGOT CASTING TOOLING AND PROCESS OPTIMIZATION

ESR MELTS USING MOVABLE MOLD

Number of Melts - Six (6)

Mold Sizes - 6" dia., 8" dia., and 10" dia.

Electrodes - (a) Mild steel 2-3/4" RCS bars in 6" Dia. mold

(b) Inco 82 - 3-1/2" RCS bars in 8" mold

(c) 4340 and maraging steel 6 inch round bars in 10" dia. mold

Fluxes Used - 70 CaF_2, 30 Al_2O_3

70 CaF_2, 20 Al_2O_3, 10 CaO

50 CaF_2, 20 Al_2O_3, 20 CaO, 10 MgO

Voltage - 38-43 Volts

Current - 3850 amps - 6" dia. ingots

4600 amps - 8" dia. ingots

5800 amps - 10" dia. ingots

HOLLOW INGOT MELTS

MELT I

Mold Size - 16 inch dia.

No. of Electrodes - three (3)

Size of Electrodes - 2" x 4" x 100 (forged flats)

TABLE I (Continued)

Flux	-	70 CaF_2, 20 Al_2O_3, 7 CaO, 3 MgO
Weight of Flux	-	110 pounds
Mandrel (32" long)	-	3" dia. tapered to 2-5/8" dia.
Mandrel Movement	-	1/8" every two minutes at first and 1/4" every three minutes.
Mandrel Rotation	-	All through melting
Voltage	-	39-41 Volts
Current	-	10,200 amps at first and then gradually lowered to 9,200 amps
Ingot Weight	-	Approx. 530 pounds
Result	-	Unsuccessful melt because metal ran into the mandrel hole at some point during the melt.

MELT 2

Mold	-	16 inch dia.
No. of Electrodes	-	four (4)
Size of Electrodes	-	2" x 4" x 96" (forged flats)
Flux	-	70 CaF_2, 20 Al_2O_3, 6 CaO, 4 MgO
Mandrel	-	3-1/2" dia. tapered to 3" dia. (24" long)
Mandrel Movement	-	1/8" per minute lift
Mandrel Rotation	-	Only during charging of molten flux and ESR melt initiation.
Voltage-Stabilized	-	39-40 Volts
Current	-	10,4000 amps all through the melt
Ingot Weight	-	Approx. 600 pounds
Result	-	Successful melt

TABLE I (Continued)

MELT 3

Mold	- 16 Inch dia.
No. of Electrodes	- Four (4)
Size of Electrodes	- 2-1/2" x 4-1/2" x 120" (cast flats)
Flux	- 60 CaF_2, 22 Al_2O_3, 12 CaO, 5 MgO
Mandrel	- 4" dia., 16" long
Mandrel Movement	- 1/4" per minute during first 10 minutes and 1/8" per minute
Mandrel Rotation	- Not used
Voltage	- 41-42 Volts
Current	- 11,000 amps
Ingot Weight	- 112 pounds
Result	- The cast electrodes burnt off unevenly; caused intermittent short circuits because of severely warped condition. Melt was stopped because of mold water leakage.

MELT 4

Mold	- 16 inch dia.
No. of Electrodes	- Four (4)
Size of Electrodes	- 2" x 4" x 96" forged and 2-1/2" x 4-1/2" cast flats welded into straight sections
Flux	- 70 CaF_2, 20 Al_2O_3, 8 CaO, 2 MgO
Mandrel (24" long)	- 3-1/2" dia. tapered to 3" dia.
Mandrel Movement	- Not moved during first 5 minutes then 1/8 inch per minute.

TABLE I (Continued)

Mandrel Rotation	-	Not Used
Voltage	-	38-39 Volts
Current	-	11,200 amps
Result	-	The mandrel showed apparent lift off but was actually welded to the contact plate. The ingot itself was being lifted. This created loss of bottom electrical contact after 15 to 20 minutes during which time an ingot weighing in excess of 300 pounds was cast. The melt was terminated because of mold water leakage and electrical contact disruption.

Title: Development of Prototype Production ESR Facilities

A maximum effort for achieving full success in this program could not be mounted because of equipment limitations and other plant constraints.

Nonetheless, the ESR hollow ingots were made with the same ease as a conventional solid ESR ingot using the same ESR system.

Further refinements of the ESR system and its auxilliary systems of locating and moving the mandrel are needed prior to carrying out additional ESR hollow ingot melts.

The successful and novel designs evolved during the course of this project work include the rotating mandrel system, low cost flat electrode casting process and the multiple electrode holder.

Project Officer: Vito J. Colangelo

VITO J. COLANGELO

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